ENGLISH TRANSLATION OF INTERNATIONAL APPLICATION AS FILED

DESCRIPTION

LAMINATED COIL

Technical Field

The present invention relates to a laminated coil and, more specifically, relates to an open magnetic path type laminated coil having an excellent direct current (DC) superposition characteristic.

Background Art

An open magnetic path type laminated coil has been proposed as a known laminated coil in order to prevent a sudden decrease in the inductance value due to magnetic saturation inside a magnetic body. As described in Patent Document 1, an open magnetic path type laminated coil includes a non-magnetic layer provided inside a laminated coil consisting of magnetic layers. According to the structure of the open magnetic path type laminated coil, magnetic fluxes leak from parts in the magnetic layers to the outside of the laminated coil, making it difficult for magnetic saturation to occur inside the magnetic body. As a result, reduction in inductance caused by a direct current is reduced, and the DC superposition characteristic is improved.

Although the open magnetic path type laminated coil according to Patent Document 1 has an excellent DC superposition characteristic, there is a problem in that the

inductance characteristic is unsatisfactory. In other words, since the non-magnetic layer is disposed at a position on the path of magnetic fluxes, the magnetic fluxes are blocked, causing reduction in inductance. To obtain desired inductance, the inductance may be increased by increasing the coil number. However, an increase in the coil number causes the direct current resistance to be significantly increased.

Patent Document 1: Japanese Examined Patent Application Publication No. 1-35483

Disclosure of Invention

The present invention provides a laminated coil that has an excellent DC superposition characteristic and that is capable of suppressing the reduction of inductance while reducing the direct current resistance.

A laminated coil according to the present invention includes: (a) a laminated body including magnetic body sections provided on both main surfaces of a non-magnetic body section, the magnetic body sections formed by stacking a plurality of magnetic layers, the non-magnetic body section including at least one layer of a non-magnetic layer; and (b) a coil including coil conductors provided in the laminated body, the coil conductors being helically connected; wherein, (c) the conductor width of at least one of the coil conductors provided inside the non-magnetic body sections and the coil conductors provided on both main

surfaces of the non-magnetic body sections of the coil conductors provided in the laminated body is greater than the conductor width of the other coil conductors.

Since the conductor width of at least one of the coil conductors provided inside the non-magnetic body sections and the coil conductors provided on both main surfaces of the non-magnetic body sections is greater than the conductor width of the other coil conductors, the direct current resistance can be reduced. Since coil conductors having a great conductor width are provided inside the non-magnetic body sections and/or on both main surfaces, inductance can be reduced even when the conductor width of the coil conductors is increased.

More specifically, in general, if the conductor width of the coil conductors is increased, magnetic fluxes of the coil is blocked by the coil conductors having a great conductor width and the inner circumference of the coil is reduced such that the amount of magnetic fluxes of the coil is reduced. Therefore, inductance is reduced. However, even if the conductor width of the coil conductors of the non-magnetic body section is increased, the amount of magnetic fluxes of the coil blocked by increasing the conductor width of the coil conductors is significantly small since the magnetic fluxes of the coil are blocked by the non-magnetic body section from the beginning. Furthermore, even if the if the conductor width of the coil conductors is increased, the reduction in the amount of

magnetic fluxes transmitted is small compared with the reduction in the inner circumference of the coil at the magnetic body sections transmitting the magnetic fluxes because the inner circumference of the coil at the non-magnetic body section that blocks the magnetic fluxes is reduced. Thus, reduction of the induction of the entire coil can be reduced.

According to the laminated coil according the present invention, the conductor width of the coil conductors provided inside the non-magnetic body sections and the coil conductors provided on both main surfaces of the non-magnetic body sections may be greater than the conductor width of the other coil conductors. By increasing the conductor width of the coil conductors provided inside the non-magnetic body sections and the coil conductors provided on both main surfaces of the non-magnetic body sections, a plurality of coil conductors having a great conductor width is provided. Thus, the direct current resistance can be significantly reduced.

According to the laminated coil according the present invention, it is desirable that the conductor width of the coil conductors having a great conductor width is 1.05 to 2.14 times the conductor width of the other coil conductors. In this way, a coil whose reduction in inductance is reduced as much as possible and whose direct current resistance is significantly reduced can be obtained.

According to the laminated coil according the present

invention, a plurality of the non-magnetic body sections may be provided inside the laminated body. By providing a plurality of the non-magnetic body sections inside the laminated body, the amount of magnetic fluxes leaking from the non-magnetic body section to the outside of the laminated coil can be increased even more. Thus, the DC superposition characteristic can be improved.

According to the present invention, a laminated coil having an excellent DC superposition characteristic and being capable of suppressing the reduction of inductance and reducing the direct current resistance is provided, since the conductor width of the coil conductors provided inside the non-magnetic body sections and the coil conductors provided on both main surfaces of the non-magnetic body sections is greater than the conductor width of the other coil conductors.

Brief Description of the Drawings

Fig. 1 is a schematic cross-sectional view of a laminated coil according to a first embodiment of the present invention.

Fig. 2 is an exploded perspective view of a laminated coil according to the first embodiment of the present invention.

Fig. 3 is a schematic cross-sectional view of a known laminated coil.

Fig. 4 is a schematic cross-sectional view of a

laminated coil according to a first comparative example.

Fig. 5 is a schematic cross-sectional view of a laminated coil according to a third embodiment of the present invention.

Fig. 6 is a schematic cross-sectional view of a laminated coil according to a fourth embodiment of the present invention.

Fig. 7 is a schematic cross-sectional view of a laminated coil according to a fifth embodiment of the present invention.

Fig. 8 is a schematic cross-sectional view of a laminated coil according to a second comparative example.

Best Mode for Carrying Out the Invention

Embodiments of a laminated coil according to the present invention will be described below with reference to the drawings.

First Embodiment

Fig. 1 is a schematic cross-sectional view of a laminated coil according to a first embodiment of the present invention. The laminated coil includes a laminated body 9 having magnetic body sections 1 and a non-magnetic body section 2, a coil L consisting helically connected coil conductors 3 and 4 provided on the laminated body 9, and external electrodes 5. The magnetic body sections 1 are provided on both main surfaces of the non-magnetic body

section 2. The magnetic body sections 1 each consists a plurality of magnetic layers, and the non-magnetic body section 2 consists one non-magnetic layer.

As shown in Fig. 1, the coil conductors 4 are provided on both main surface of the non-magnetic body section 2. The conductor width of the coil conductors 4 is greater than that of the other coil conductors 3 having a predetermined conductor width. Since the conductor width of the coil conductor 4 is great, the direct current resistance of the laminated coil is reduced.

Since the coil conductors 4 each having a great conductor width are provided on both main surfaces of the non-magnetic body section 2, reduction of inductance can be reduced. More specifically, in general, if the conductor width of the coil conductors is increased, inductance is reduced because the amount of transmitted magnetic fluxes of the coil is reduced by being blocked by the coil conductors having a great conductor width and by reducing the inner circumference of the coil. However, according to the first embodiment, since the magnetic fluxes of the coil L are blocked by the non-magnetic body section 2 from the beginning, the amount of magnetic fluxes of the coil L that are blocked is significantly reduced by increasing the conductor width of the coil conductors 4 on both main surfaces of the non-magnetic body section 2. Even if the conductor width of the coil conductors 4 is increased, the inner circumference of the coil L in the non-magnetic body

section 2 blocking the magnetic fluxes is reduced. Therefore, reduction in the amount of the transmitted magnetic fluxes is small compared to reduction in the inner circumference of the coil L in the magnetic body sections 1 transmitting the magnetic fluxes. In this way, reduction in induction of the entire coil L can be significantly reduced.

Next, a method of producing a laminated coil is described with reference to an exploded perspective view of a laminated coil illustrated in Fig. 2.

In the method of producing a laminated coil, first, green sheets 6 consisting of a magnetic material and a green sheet 7 consisting of a non-magnetic material are produced. After forming the laminated coil, the magnetic green sheets are referred to as magnetic layers and the non-magnetic green sheet is referred to as a non-magnetic layer.

According to the first embodiment, a Ni-Cu-Zn based material is used as a magnetic material. First, a raw material including 48.0 mol% of ferric oxide (Fe_2O_3), 20.0 mol% of zinc oxide (ZnO), 23.0 mol% of nickel oxide (NiO), and 9 mol% of copper oxide (CuO) is wet prepared using a ball mill. The obtained mixture is dried and ground. The obtained powder is calcinated at 750°C for one hour. The obtained powder is mixed with a binder resin, a plasticizer, a moistening agent, and a dispersant by a ball mill. Then, defoaming is carried out to obtain slurry. The slurry is applied onto a peelable film. Then, by drying, the magnetic green sheet 6 that has a predetermined thickness is produced.

As a non-magnetic material, a Cu-Zn based material is used. The non-magnetic green sheet 7 is produced of a raw material including 48.0 mol% of Fe_2O_3, 43.0 mol% of ZnO, and 9.0 mol% of copper oxide (CuO) and by employing the same method as that of the above-described magnetic material. The relative magnetic permeability of a green sheet is 130 for the magnetic green sheet 6 and 1 for the non-magnetic green sheet 7.

Next, the green sheets 6 and 7 obtained as described above are cut into predetermined sizes. After stacking the green sheets 6 and 7, through-holes are formed at predetermined positions by employing a laser method so that the helical coil L is formed. Then, the coil conductors 3 and 4 are formed by applying conductive paste mainly consisting of silver or a silver alloy onto magnetic green sheets 6a and the non-magnetic green sheet 7 by a method of screen printing. By filling the inside of the through-holes with the conductive paste simultaneously to the production of the coil conductors 3 and 4, via-hole conductors 8 for connection can be easily formed.

Here, the coil conductors 4 having a great width are formed on both main surfaces of the non-magnetic green sheet 7. According to the first embodiment, the coil conductors 4 having a great width are produced so that the conductor width is 550 μm and the other coil conductors 3 are produced so that the conductor width is 350 μm after calcination. By forming the coil conductors 4 having a great width on both

main surfaces of the non-magnetic green sheet 7, a laminated coil capable of suppressing the reduction in inductance and reducing direct current resistance can be obtained.

Subsequently, the laminated body is produced by stacking the magnetic green sheets 6a having the coil conductors 3 on both main surfaces of the non-magnetic green sheet 7 and by disposing exterior magnetic green sheets 6b, not having coil conductors on the top and bottom. At this time, by stacking the non-magnetic green sheet 7 at a position substantially in the middle along the axial center direction of the helical coil L, the amount of magnetic fluxes leaking outside the laminated coil is increased. Thus, the DC superposition characteristic can be improved.

Then, the laminated body is pressure bonded at 45°C at a pressure of 1.0 t/cm^2 and cut into pieces of 3.2×2.5×0.8 mm by a dicer or a guillotine cutter to obtain unfired bodies of the laminated coil. Subsequently, binder removal and firing of the unfired bodies are carried out. For binder removal, the unfired bodies are fired in a low oxygen atmosphere at 500°C for 2 hours. For firing, the bodies are fired in an atmosphere of 890°C for 150 minutes. Finally, conductive paste mainly consisting of silver is applied by immersion to the end surfaces where the lead electrodes 4a and 4b are exposed. After drying the bodies at 100°C for 10 minutes, baking is carried out at 780°C for 150 minutes. In this way, the laminated coil according to the first embodiment is obtained.

Table 1

	Rdc (mΩ)	Inductance (μH)
Conventional Example	185	2.00
First Embodiment	166	1.91
First Comparative Example	150	1.56

Table 1 shows the results of tests carried out to confirm the advantages of the laminated coil according to the first embodiment produced as described above. As shown in Fig. 3, according to the laminated coil according to the conventional example, the conductor width of each of the coil conductors 13 provided on magnetic body sections 11 and a non-magnetic body section 12 is 350 μm. As shown in Fig. 4, according to the laminated coil according the comparative example, the conductor width of coil conductors 24 provided on magnetic body sections 21 and a non-magnetic body section 22 is 550 μm. For every laminated coil, the coil number of the helical coil L is 5.5 turns, and the size of the laminated coil is 3.2×2.5×2.5 mm.

According to Table 1, for the laminated coil according to the first embodiment, the direct current resistance is reduced and the reduction of inductance is small. More specifically, the direct current resistance of the conventional example is 185 mΩ whereas the direct current resistance of the first embodiment is 166 mΩ and is reduced by 10%. The inductance of the conventional example is 2.0

μH whereas the inductance of the first embodiment is 1.91 μh and is only reduced by 4.5%. In contrast, according to the comparative example in which the conductor width of all coil conductors is increased, the direct current resistance is reduced by 18% to 150 mΩ and the inductance is greatly reduced by 22% to 1.56 μH. In this way, according to the first embodiment, the reduction of inductance can be suppressed while the direct current resistance is reduced by increasing the conductor width of the coil conductors 4 because the coil conductors 4 having a great conductor width are provided on both main surfaces of the non-magnetic body section 2 that is blocking the magnetic fluxes.

Table 2

	Conductor Width of Coil Conductors disposed on Both Main Surfaces of Non-magnetic Body	Conductor Width Ratio	Rdc (mΩ)	Inductance
Conventional Example	350 μm	1.00	185	2.00
Specimen 1	357 μm	1.02	184	2.00
Specimen 2	368 μm	1.05	183	1.99
Specimen 3	450 μm	1.29	176	1.96
Specimen 4	550 μm	1.57	166	1.91
Specimen 5	650 μm	1.86	157	1.86
Specimen 6	750 μm	2.14	147	1.79
Specimen 7	850 μm	2.43	138	1.71

Next, Table 2 shows the evaluation results of specimens 1 to 7, wherein the conductor widths of the coil conductors 4 provided on both main surfaces of the non-magnetic body section 2 are changed. The specimens 1 to 7 were produced so that the conductor widths of the coil conductors 4 provided on both main surfaces of the non-magnetic body section 2 differ and are 357, 368, 450, 550, 650, 750, and 850 μm, respectively. The conductor width (i.e., 350 μm) of the laminated coil according to the conventional example, shown in Fig. 3.

For the specimens 2 to 6, the direct current resistance

is reduced and the inductance values are desirable. The specimen 1 (conductor width ratio 1.02) exhibited a significantly small reduction of less than 1% in the direct current resistance. For the specimen 7 (conductor width ratio 2.43), reduction in the inductance value compared with that of the conventional example is significantly reduced to 14.5%.

Second Embodiment

The structure of a laminated coil according to a second embodiment of the present invention is the same as the structure of the laminated coil according to the first embodiment illustrated in Fig. 1. However, for a laminated coil according to the second embodiment, the conductor width of the coil conductors 4 disposed on both main surfaces of the non-magnetic body section 2 is 750 μm, and the conductor width 3 of the coil conductors 3 that are not disposed on both main surfaces of the non-magnetic body section 2 is 350 μm. The conventional example, shown in Table 3 below, represents a laminated coil whose coil conductors 13 provided on magnetic body sections 11 and a non-magnetic body section 12, as shown in Fig. 3, all have a conductor width of 350 μm. The second comparative example, as shown in Fig. 8, represents a laminated coil whose coil conductors 34 that are not provided on both main surfaces of a non-magnetic body section 32 (provided inside magnetic body sections 31) have a conductor width greater than that of

other coil conductors 33. The conductor width of the coil conductors 34 having a great conductor width is 750 μm. The conductor width of the coil conductors 33 is 350 μm.

Table 3

	Rdc (mΩ)	Inductance (μH)
Conventional Example	185	2.00
Second Embodiment	147	1.79
Second Comparative Example	147	1.53

For the laminated coil according to the second embodiment, as shown in Table 3, the direct current resistance is reduced compared with the conventional example because the conductor width of the coil conductors 4 that are disposed on both main surfaces of the non-magnetic body section 2 is great. Furthermore, for the laminated coil according to the second comparative example, the direct current resistance is reduced compared with the conventional example because the conductor width of the coil conductors 34 having the same coil number as that of the laminated coil according to the second embodiment is increased. The inductance of the laminated coil according to the second embodiment is 1.79 μh and is only reduced by about 10% compared with the conventional example. The inductance of the laminated coil according to the second comparative example is 1.53 μm and is reduced by about 23% compared with

the conventional example. The reduction of the inductance of the laminated coil according to the second embodiment can be suppressed because the coil conductors 4 having a great conductor width are provided on both main surfaces of the non-magnetic body section 2 that blocks the magnetic fluxes.

Third Embodiment

Fig. 5 illustrates a schematic cross-sectional view of a laminated coil according to a third embodiment of the present invention. In Fig. 5, the components that are the same as or correspond to those in Fig. 1 are represented by the same reference numeral as those in Fig. 1, and descriptions thereof are not repeated.

In the laminated coil according to the third embodiment, the coil conductors 4 are formed inside the non-magnetic body section 2. The conductor width of the coil conductors 4 is greater than the conductor width of the other coil conductors 3. Similar to the first embodiment, the laminated coil according to the third embodiment is produced through steps of stacking and pressure bonding green sheets having coil conductors, cutting the green sheets into chips, and forming external electrodes.

By providing the coil conductors 4 having a great conductor width, the direct current resistance can be reduced. Furthermore, by forming the coil conductors 4 having a great conductor width inside the non-magnetic body section 2, the reduction of inductance can be reduced.

Fourth Embodiment

Fig. 6 illustrates a schematic cross-sectional view of a laminated coil according to a fourth embodiment. In Fig. 6, the components that are the same as or correspond to those in Fig. 1 are represented by the same reference numeral as those in Fig. 1, and descriptions thereof are not repeated.

In the laminated coil according to the fourth embodiment, the coil conductors 4 are formed inside the non-magnetic body section 2 and on both main surfaces of the non-magnetic body section 2. The conductor width of the coil conductors 4 is greater than the conductor width of the other coil conductors 3.

By providing the coil conductors 4 with a great conductor width, the direct current resistance can be reduced. In particular, according to the fourth embodiment, since three layers of the coil conductors 4 having a great conductor width are provided, the direct current resistance can be significantly reduced. By forming the coil conductors 4 having a great conductor width inside the non-magnetic body section 2 and on both main surfaces of the non-magnetic body section 2, the reduction of inductance can be reduced.

Fifth Embodiment

Fig. 7 illustrates a schematic cross-sectional view of

a laminated coil according to a fifth embodiment. In Fig. 7, the components that are the same as or correspond to those in Fig. 1 are represented by the same reference numeral as those in Fig. 1, and descriptions thereof are not repeated.

In the laminated coil according to the fifth embodiment, two of the non-magnetic body sections 2 are provided inside the laminated body 9. The coil conductors 4 are provided on both sides of the non-magnetic body sections 2. The conductor width of the coil conductors 4 is greater than the conductor width of the other coil conductors 3.

Since two of the non-magnetic body sections 2 are provided inside the laminated body 9, the amount of magnetic fluxes leaking outside the laminated coil can be increased, and the DC superposition characteristic can be improved. By providing wide coil conductors 4, the direct current resistance can be reduced. In particular, according to the fifth embodiment, since four layers of the coil conductors 4 having a great conductor width are provided, the direct current resistance can be significantly reduced. By providing coil conductors 4 having a great conductor width on both main surfaces of the non-magnetic body sections 2, the reduction of inductance can be reduced.

Other Embodiments

The laminated coil according to the present invention is not limited to the above-described embodiments, and various modifications may be employed within the scope of

the invention.

For example, the conductor width of one of the coil conductors provided on both main surfaces of the non-magnetic body section may be great. The conductor width of at least one of the coil conductors provided inside the non-magnetic body section and both main surfaces of the non-magnetic body section may be greater than the conductor width of the other coil conductors in the main sections.

Industrial Applicability

As described above, the present invention may be employed to an open magnetic path type laminated coil and, in particular, is advantageous in that the DC superimposition characteristic is excellent, reduction in inductance can be reduced, and direct current resistance can be reduced.